"PROPERTIES OF R-41 SHEET,

A VACUUM MELTED, NICKEL BASE ALLOY"

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SUBJECT: "Properties of R-41 Sheet, A Vacuum Melted, Nickel Base Alloy"

ABSTRACT

The mechanical properties (F_{ty}, F_{tu}, elongation, and notched/unnotched tensile ratios) were determined at +78, -100, -320, and -423°F on R-41 (Rene 41) 0.020" sheet material in both the as-received and age-hardened conditions. The data indicate that R-41 sheet metal in the age-hardened condition remains tough at cryogenic temperature as determined by notched/unnotched tensile ratios. R-41 alloy is one of the highest strength materials available for structural applications at 1600-1800°F, and would thus be especially suitable for applications where the same component would be exposed initially to liquid oxygen or liquid hydrogen temperatures and then undergo heating in service to elevated temperatures while subjected to high stresses. Supplementary information on the chemistry, available forms, heat treatments, fabrication (forging, welding, machining, etc.), and physical and mechanical property data is included. Seven references on R-41 alloy which are available in the Materials Research Group are listed in Appendix A.

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INTRODUCTION

Progress in the missile and space craft field is dependent upon the engineering materials available and upon the information known about these materials. Of particular importance are the very low and high temperature mechanical and physical properties since these materials may be subjected to very low temperatures by use of cryogenic propellants and to high temperatures by several means (atmospheric friction, radiation, and heating by engines or electrical components). In order to obtain maximum efficiency, missile designs incorporate the use of the highest strength/density material which is capable of withstanding the severest environments imposed upon it. There are a limited number of materials which may be severely stressed in the temperature range of 1600° - 1800°F because they have either essentially lost all of their mechanical strength (many alloys such as aluminum, copper, and magnesium alloys, etc. are molten and/or vaporizing) or they are oxidizing rapidly which make them unsuitable for engineering application. Likewise, there are a limited number of alloys which may be used for structural application at very low temperatures because many materials exhibit embrittlement which causes catastrophic failure at stress levels well below design strengths.

The mechanical properties of a large number of engineering materials have been determined at cryogenic temperatures. These materials include aluminum alloys, titanium alloys, nickel and cobalt base alloys, as well as many stainless steels. Most of these alloys, however, may not be used at high temperatures (1600°F and above). R-41 alloy (or more commonly known as Rene' 41) is one of the higher strength alloys in the 1600°-1800°F range and a large amount of data has been compiled on mechanical and physical properties of this material at high temperatures (see Appendix A for references).

OBJECT

It was the purpose of this investigation to determine if R-41 alloy sheet material, which has superior mechanical properties at high temperatures, would be suitable for structural application at cryogenic temperatures (down to -423°F).

MATERIALS

The R-41, a vacuum melted, nickel base alloy, used in this investigation was supplied by Haynes Stellite Company, in 0.020" thick sheet, heat number TV-592.

The material was received in the solution treated (1975°F rapid quench) condition. Chemical composition limits for R-41 wrought and cast alloys as well as the certified chemical analysis of the material used in this investigation are presented in Table 1. The as-received material had a R_b hardness of 93. Part of the material was solution treated (1950°F for 30 min., air cool) and age-hardened (1400°F for 16 hours, air cool) under an inert atmosphere by Materials Research Group heat treat facilities. Very little or no surface tarnish resulted from heat treatment. Hardness was R_c 39. Mechanical property data determined at room temperature by the Materials Research Group duplicated the certified data supplied by the vendor.

PROCEDURE

Blanks for tensile specimens, 9" x 1½", were identified and sheared in directions both longitudinal and transverse to the direction of rolling. Half of the specimen blanks were age-hardened, and both smooth (MRG-D-1) and notched (MRG-D-10, Notch "A") tensile specimens were machined. A minimum of three tensile tests in the longitudinal and two tests in the transverse directions were performed on both smooth and notched specimens at room temperature (78°F), -100°F (alcohol and dry ice), -320°F (liquid nitrogen), and -423°F (liquid hydrogen). Strain measurements were made by use of extensometers (cryo-extensometer at low temperatures) and a continuous stress strain recorder. Total elongation was determined by scribe marks made with a precision block and read under 10X magnification. Strain rates were maintained at 0.001"/"/min. until 0.2% offset yield and then 0.15"/min. until fracture. The 50,000# Baldwin testing machine, strain recorder, strain pacer, and extensometers are periodically checked and approved by CVA standards laboratory.

RESULTS AND DISCUSSION

The results of the mechanical property testing on the as-received material are presented in Table 2. As may be seen, the solution treated R-41 sheet material suffers from rather low notched/unnotched tensile ratios at all testing temperatures. Also, a large scatter exists in the notched tensile data at -423°F, this being indicative of embrittlement. The low yield and tensile strengths of the as-received R-41 alloy make it unfavorable for applications requiring a material with high strength/density.

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The mechanical properties of the age-hardened R-41 sheet material at +78, -100, -320, and -423°F are presented in Table 3. The notched/unnotched tensile ratio increases from 0.91 at 78°F to 0.99 at -423°F. These data plus the increase of notched tensile strength with reduction in temperature and good ductility as measured by elongation indicate that R-41 sheet in the age-hardened condition remains tough from room temperature to nearly absolute zero. The relatively high yield (134-138 ksi) and tensile (174-181 ksi) strengths at 78°F makes R-41 alloy competitive with other materials. The density of R-41 is 0.296 pounds/in^3 (density of 301 CRES is 0.288 #/in^3). For those applications which require a structural material to be used at both high and very low temperatures, R-41 alloy is most attractive.

SUPPLEMENTARY INFORMATION

R-41 alloy is available as sheet, plate, bar, wire, or forging stock as well as investment castings (see Table 4) at a cost comparable with many other nickel or cobalt base and titanium base alloys.

A variety of heat treatments have been successfully employed, the more common of which are listed below.

A. Solution treat at 1975° ± 25°F, rapid quench. (Normal "as-received" condition)

B. Heat treatment A plus solution treat at 1950°F for 30 min., air cool; age at 1400°F for 16 hours, air cool.

C. Heat treatment A plus solution treat at 2150°F for 30 min., air cool; age at 1650°F for 4 hours, air cool.

Rapid quenching instead of air cooling for heat treatments B and C have shown some advantages, especially for cast material. In general, higher solutioning temperatures result in better room temperature ductility and higher rupture strength at elevated temperatures, whereas lower solutioning temperatures result in higher tensile strengths. The material may be annealed for maximum formability by treating it at 2150°F for 30 min., water quench. Stress relieving after machining, cold working, or welding may be obtained by re-solutioning with subsequent aging if desired.

R-41 is one of the strongest high temperature materials that can be successfully formed and welded(references, Appendix A). The alloy may be readily formed in the annealed condition. Distortion is comparatively low if the material is subsequently solution treated.

R-41 may be successfully forged, however small reductions should be taken. Starting temperature should be 2150°F (2195°F max.) and finishing temperature 1950°F min. to prevent cracking. The alloy has been successfully cast. Cold working with subsequent heat treatment improves the as-cast mechanical properties.

The alloy may be machined (preferably in the fully aged condition since the soft solutioned condition is "gummy") by either carbide or high speed tools. Tool geometry, depth of cut, feed, and speed are available for satisfactory machining. R-41 can be inert-arc welded, manually or by machine, and with or without filler metal. Spot welds can be made on conventional equipment. Properly performed welds are ductible, 90% efficient, and are not crack sensitive. Welding should be done in the fully solutioned condition with subsequent solution treatment for homogenization and stress relief followed by aging for maximum strength.

A large amount of physical and mechanical property data on R-41 alloy are available. Tensile, fatigue, creep, creep-rupture, and elastic properties are available at various temperatures (generally 70° to 1800°F). The alloy is highly corrosion and oxidation resistant.

SUMMARY

1. R-41 sheet material in the solution treated condition shows little promise for structural applications at cryogenic temperatures due to embrittlement and low yield strengths.

2. R-41 sheet material in the age hardened condition (1950°F, 30 min., air cool) has a high strength/density ratio and remains tough at very low temperatures, as determined by notched/unnotched data, fracture appearance, and ductility.

3. R-41 alloy is commercially available in many forms at costs comparable with other engineering materials.

4. R-41 alloy has attractive physical and mechanical properties (tensile, creep, creep-rupture, fatigue, elastic, etc.).

5. R-41 alloy is one of the highest strength materials available in the 1600°-1800°F temperature range.

6. R-41 alloy is highly corrosion and oxidation resistant.

7. R-41 alloy may be readily formed and fusion or spot welded with available production equipment.

TABLE 1

Chemical Compositions of R-41

Alloying Element	Wrought Alloy* Limits,%	Cast Alloy* Limits,%	Material Used in This Investigation Heat TV-592
Chromium	18.00-20.00	18.00-20.00	19.54
Iron	5.00 max.	5.00 max.	0.46
Carbon	0.12 max.	0.06-0.12	0.09
Silicon	0.50 max.	0.50 max.	0.09
Cobalt	10.00-12.00	10.00-12.00	11.20
Manganese	0.10 max.	0.50 max.	0.02
Titanium	3.00-3.30	3.00-3.30	3.07
Molybdenum	9.00-10.50	9.00-10.50	10.02
Aluminum	1.40-1.60	1.50-1.80	1.41
Boron	0.003-0.010	0.003 max.	0.006
Nickel	Balance	Balance	Balance
Sulphur	0.015 max.	-	0.008

* From Haynes Stellite Company, Haynes Alloy No. R-41 No. F-30, 155.

TABLE 2

Mechanical Properties of R-41 (As-Received)*

0.020" Sheet, Haynes Stellite Co., Heat TV-592

Test Temp.	Direction	F_{ty} ksi	F_{tu} ksi	e %	Notched T.S. (K_t=6.3) ksi)	Notched/Unnotched Tensile Ratio
+78°F	Long.	70.0	133	49	107	
	"	72.8	135	47	105	
	"	73.3	134	47	110	
	Average	71.9	134	48	107	0.80
+78°F	Trans.	81.8	133	44	111	
	"	81.8	133	48	111	
	Average	81.8	133	48	111	0.83
-100°F	Long.	83.4	151	51	121	
	"	85.1	151	52	121	
	Average	84.3	151	52	121	0.80
-100°F	Trans.	112	151	49	120	
	"	83.4	148	50	117	
	"	78.7	153	49		
	Average	91.4	151	49	119	0.79
-320°F	Long.	101	179	52	140	
	"	93.2	178	50	140	
	"	88.2	177	50		
	Average	94.1	178	51	140	0.79
-320°F	Trans.	89.6	177	47	142	
	"	93.7	175	47	143	
	Average	91.7	176	47	143	0.81

TABLE 2 (Cont.)

Test Temp.	Direction	F_{ty} ksi	F_{tu} ksi	e %	Notched T.S. (K_t=6.3) ksi	Notched/Unnotched Tensile Ratio
-423°F	Long.	119	222	48	169	
	"	125	234	50	132	
	"	135	212	35	136	
	Average	126	223	44	146	0.65
-423°F	Trans.	113	192	43	169	
	"	107	202	45	203	
	Average	110	197	44	186	0.94

* Solution treated at 1975°F, rapid quench

TABLE 3

Mechanical Properties of R-41 (Age Hardened)*

0.020" Sheet, Haynes Stellite Co., Heat TV-592

Test Temp.	Direction	F_{ty} ksi	F_{tu} ksi	e %	Notched T.S. (K_t=6.3) ksi	Notched/Unnotched Tensile Ratio
+78°F	Long.	-	177	14	162	
	"	138	184	21	167	
	"	138	183	20	163	
	Average	138	181	18	164	0.91
+78°F	Trans.	134	172	10	164	
	"	134	176	14	162	
	Average	134	174	12	163	0.94
-100°F	Long.	-	192	13	173	
	"	148	192	13	173	
	Average	148	192	13	173	0.90
-100°F	Trans.	145	179	9	174	
	"	145	182	9	176	
	"	145	187	11		
	Average	145	183	10	175	0.96
-320°F	Long.	162	203	9	188	
	"	161	199	9	190	
	"	160	203	10		
	Average	161	202	9	189	0.94
-320°F	Trans.	162	196	7	189	
	"	162	196	7	182	
					189	
	Average	162	196	7	187	0.98

TABLE 8 (Cont.)

Test Temp.	Direction	F_{ty} ksi	F_{tu} ksi	e %	Notched T.S. (K_t=6.3) ksi	Notched/Unnotched Tensile Ratio
-423°F	Long.	182	202	6	207	
	"	178	215	7	215	
	"	178	219	6	206	
	Average	179	212	6	209	0.99
-423°F	Trans.	177	206	5	190	
	"	170	205	5	219	
	Average	174	206	5	205	1.00

* Solution treated and aged for 30 min. at 1950°F air cool, plus 16 hours at 1400°F air cool.

TABLE 4

Available Forms of R-41 Alloy*

Sheet	Thickness: 0.020 in. to 0.1875 in. Maximum size: 48 in x 144 in. Usual rolling size: 36 in. x 96 in. Also available upon request: Thickness of 0.010 in. to 0.0199 in. As-cold-reduced, bright finish sheet Unless otherwise specified sheet will be furnished in the solution treated condition.
Plate	Thickness: 3/16 in. to 2 in. inclusive. Maximum width: 48 in. Maximum length: 132 in. Maximum weight: 800 lb.
Bar	Nominal diameter: ½ in. to 2 in. - maximum mill length: 10 ft. Nominal diameter: 2 in. to 3½ in.-Maximum mill length: 8 ft.
Wire	Nominal diameters: 1/16 in. to ¼ in.
Forging Stock	Maximum billet diameter: 8 in. Shape: Tuned and ground rounds.
Investment Castings	

* From Haynes Stellite Company, Haynes Alloy No. R-41
No. F-30, 155

Appendix A

References to Publications on R-41*

1. , Haynes Alloy No. R-41, Bulletin No. F-30, 155. Haynes Stellite Company, Division of Union Carbide Corporation.

2. , Rene' 41, Vacuum Melted Alloy, Bulletin No. VM-107, Metallurgical Products Department, General Electric Company, May 1958.

3. G. Sachs and R. Ford Pray II, Air Weapons Materials Application Handbook Metals and Alloys, ARDC TR59-66 under USAF Contract No. AF18(600)-1794, 1st Edition, Syracuse University Research Institute, Dunbar, 1959.

4. A. Giunteli, Short-Time Elevated Temperature Mechanical Properties of R-235, D-979, Rene'41, and Unitemp 212 High Temperature Alloys, Report No. MP 58-337, Materials & Processes Laboratory, Convair, San Diego, A Division of General Dynamics Corporation, February, 1959.

5. , Rene'41, One of the Strongest Materials Available for Use in the Temperature Range 1200°F-1800°F, Series No. 80, Cannon-Muskegon Corporation.

6. , Comparative Properties Data on Some High Temperature Alloys, Investment Cast and Wrought, Haynes Stellite Company, a Division of Union Carbide Corporation, March, 1959.

7. J. R. Kattus, Tensile and Creep Properties of Structural Alloys Under Conditions of Rapid Heating, Rapid Loading, and Short-Times at Temperature, 3962-807-2-I, Southern Research Institute, April, 1959.

* These publications are available in the Materials Research Group, 595-20